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| <p>(54)Title: POROUS SPHERICAL POLYVINYL ACETAL PARTICLES, PROCESS FOR PRODUCING THE SAME, AND MICROBIAL CARRIERS</p> <p>(54)発明の名称 ポリビニルアセタール系多孔性球状粒子及びその製造方法並びに微生物担体</p> <p>(57) Abstract</p> <p>Porous spherical particles being excellent in mechanical strength and abrasion resistance, having an affinity for microorganisms, and being appropriately usable as microbial carriers; and a process whereby these particles can be easily produced at a high productivity. The above-mentioned particles comprise a polyvinyl acetal resin as the skeleton and have a porosity of 50 to 95 % and a degree of acetalization of 30 to 85 % by mol. The above-mentioned process comprises dropping an aqueous solution containing a mixture dissolved therein of polyvinyl alcohol, a water-soluble polymer capable of gelling via an ion exchange reaction and aldehydes into an acidic solution and solidifying the droplets through the reaction between the polyvinyl alcohol and the aldehydes. The particles are appropriate as microbial carriers, in particular, those to be used in waste water treatment tanks of the fluidized bed type.</p> |           |  |

## **Porous spherical particles and the preparation process for preparing thereof**

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### **Abstract**

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Porous spherical particles with mechanical strength and high antiabrasity and microbial affinity, useful as biological carrier. The process for preparing them with simplicity and high productivity is also disclosed. The porous spherical particles have polyvinyl acetal resin as skeleton, the porous rate being 50-95%, and acetalation 30-85 mol%. The particles can be made by dropping polyvinyl alcohol an aqueous solution of water solubity high molecular polymer and aldehydes into an acid solution and gelatin by the reaction of polyvinyl alcohol and aldehyde.

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## **SPECIFICATION**

### **Polyvinyl acetal porous spherical particles, process for producing the same, and microbial carriers**

#### **Technical field**

The present invention relates to porous spherical particles and process for producing the same. More specifically, the present invention relates to porous spherical particles having a polyvinyl acetal resin as a skeleton suitably used in particular as a microbial carrier of the fluidized bed type, and the process for producing the porous spherical particle which can produce the porous spherical particles suitably.

#### **Background art**

The method to obtain a product by filling microorganisms or an enzyme in a reactor and using the reaction by the microorganisms and enzyme is so-called bioreactor. It is conventionally used in the manufacturing field of food, medicines, and chemicals, or processing field of the sewer, drainage, and waste gas and the like. In recent years, various kinds of means for filling this microbial biocatalyst in a reaction vessel with a high density also studied for the further increase in efficiency of processing.

One of the most typical means is a method for carrying microorganisms to a spherical carrier. In particular, there are two methods, one is a biomembrane method by which microorganisms are carried on the carrier surface and biomembranes are used, and the other is a comprehensive immobilized microorganism method by which microorganisms are immobilized inside a carrier. Raw materials of these carriers are polymers and inorganic substances. Moreover, as the use form of the carrier, there are fixed bed type using a carrier immobilized inside the reaction vessel, and fluidized bed type using a carrier while allowing it to flow.

Because flowability and specific gravity are important for the carrier used in a fluidized bed type especially, a spherical carrier of polymer is generally used rather than an inorganic carrier. Various methods using a raw material of this carrier, for example, such as polyvinyl alcohol gel (PVA gel), acrylamide gel, and polyethylene glycol and

porous spherical particles such as polyethylene, polyurethane, polyvinylidene chloride, and cellulose are proposed.

Conventionally, these spherical particles were produced as follows. That is, into an aqueous solution in which a raw material is dissolved, additives such as a pore-forming agent, a cross linking agent, and a catalyst are kneaded, the kneaded mixture is poured into a large reaction die, and insolubilized by reacting the mixture in a hot water bath or an air bath. A pore-forming agent is extracted and removed by washing with water, thereby obtaining a block polymer porous body. Then, this large block polymer porous body is made to be sheet form by slicing it with a thickness of several millimeters, further this sheet form porous bodies are made to be string form by cutting this sheet body per several millimeters, and finally cube particles of several millimeters cubic are produced by cutting these string-like polymer porous bodies with a length of every several millimeters. Moreover, above -mentioned large block polymer porous body is made to be sheet form by slicing it with a thickness of several millimeters, and spherical porous bodies are also obtained by piercing this sheet body per several millimeters using a punch die.

By the way, as a property desired for microbial carrier, flowability, specific gravity, abrasion resistance, weather(light)-proof, biolysis resistance, etc. are exposed other than affinity to microorganisms, and these performances vary depending on types of carrier. Although the gel

Among the above carrier species, though a gel carrier is excellent in affinity to microorganisms, its mechanical strength is low and in particular abrasion resistant performance is remarkably inferior. Therefore, this carrier is easy to wear by the rub of carriers each other and the friction with an inner wall of a reaction vessel which are generated at the time of flowing carriers, and the life span of the carrier is short. Moreover, porous spherical particles such as polyethylene and polyurethane have problems that weather proof performance is not so high and, as for cellulose, there was a problem that the carrier tends to break down in the long-term use since cellulose itself is easy to suffer from biolysis, and consequently its life span was short. Furthermore, it is important to obtain porous spherical particles having a uniformity particle size as possible as near true sphere from viewpoints of filling to a container, improvement in wear proof, and improvement in flowability as a microbial carrier of a fluidized bed type. However, since

the conventional porous spherical particles are the cubic particles, this point was not necessarily satisfied.

Moreover, because the conventional porous spherical particles were produced by the producing method mentioned above, at least several hours was required for reaction, and the forming process consisting of as many as three steps was also required after reaction. Therefore, at least two days or more were necessary for forming a uniform spherical particle of several millimeters. When piercing by a punch die, since there were many cases that several millimeters of particles were clogged into the die, the post treatment for removing this clogged particles was necessary. As a block porous body was sliced, cut or pierced in the post processing, the yield was also low.

Considering above points, there is a method for pulverizing a block polymer body as it is without slicing using a grinding machine, etc. as a means for largely shortening the time of post processing and improving the yield. Although processing time can be largely shortened and the yield can be improved by this method, it was difficult to obtain porous spherical particles having a uniformity particle size.

Furthermore, the large space is required for reaction vessel in proportion to increase of production quantity because reaction is performed for every type in any of the above-mentioned methods. Therefore, there was also a problem that limitation was present in production quantity due to a limited equipment, thereby productivity was poor.

The object of the present invention is to provide the porous spherical particles which has a high mechanical strength, abrasion resistance, and affinity to microorganisms, and which are suitably used as a microbial carrier, especially a microbial carrier for a fluidized bed type. Moreover, the another object of the present invention is to provide a process for producing porous spherical particle which can simply produce porous spherical particles of a uniformity particle size as possible as near true sphere with a high productivity.

### **Disclosure of the invention**

As a result of earnestly studying in order to solve the above-mentioned problem, the present inventors obtained the knowledge that a material excellent in abrasion resistance, weather light-proof, biolysis resistance, flowability, and the affinity to microorganisms could be obtained when porous spherical particles having a polyvinyl acetal resin as a

skelton, particularly spongy porous spherical particles having a polyvinyl acetal resin as a skelton, and more particularly porous spherical particles having a polyvinyl formal resin as a skelton are used.

The present invention is to provide porous spherical particles having a polyvinyl acetal resin as a skeleton. Moreover, the present invention is to provide porous spherical particles consisting of a spongy polyvinyl acetal resin having a communicating hole as a pore. Therefore, when polyvinyl acetal porous spherical particles, in particular, porous spherical particles of polyvinyl formal (PVF) are used as a carrier of microorganisms, a microbial carrier excellent in abrasion resistance, weather light-proof, biolysis resistance, flowability, and affinity to microorganisms can be obtained.

Since such porous spherical particles are not hydrate gel structure but spongy porous body having a skeleton structure of polyvinyl acetal, it is excellent in abrasion resistance and mechanical strength compared with those of gel body. Therefore, the porous spherical particles of the present investigation is suitably used for solution holding material and vegetable support material in hydroponics of corps, medium for animal and plant cells, artificial sphagnum, and soil improvement material, a piping washing member, filter medium, water absorbing material, etc. other than using as a microbial carrier. In addition, as a special example of using the particles, it is also possible to use as an underwater fluidized-type-washing member or an underwater fluidized-type massage member. Here, an underwater fluidized-type washing member means the washing member for washing the surface of vegetables by putting it in water with vegetables, generating bubbles from the bottom of a water tank, stirring the whole with bubbles thereby contacting it with vegetables, in order to wash vegetables having a fragile surface or vegetables having a very uneven surface and the like. Moreover, the underwater fluidized-type massage member means the member to provide massage effect to human body, which is the member for providing stimulus to skin and thereby obtaining massage effect by making contact it with human body whole flowing particles in a tank such as bathtub.

Since, particularly, the microbial carrier has affinity to microorganisms and excellent flowability, it can be suitably used for fluidized bed type. More particularly, as for porous spherical particles having a polyvinyl acetal resin as a skeleton and having a uniformity

particle size near true sphere, its mechanical strength and abrasion resistance are excellent, therefore filling to a container and its flowability as a microbial carrier are further improved.

Moreover, as a process for producing these porous spherical particles, the present inventors found out that porous spherical particles having a polyvinyl acetal resin as a skeleton can be obtained by the following procedure: A solution containing water soluble polymer having a property of gelatinizing in an acidic solution, polyvinyl alcohol and aldehydes is dropped into an acidic solution, the droplets are gelatinized and polyvinyl alcohol and aldehydes are made to be reacted in these droplets.

Since oil droplets of the stock solution forming particles directly become particles by contacting with a reaction mixture by this producing method, acetalized treatment and forming process of spherical particles can be performed at the same time. In addition, the form of the droplet does not collapse because it contains water soluble polymer gelatinized when it contacts with acid, a catalyst for acetalizing. Therefore, the porous spherical particles having a uniform particle size near true sphere can be simply produced with a high productivity without requiring many steps as the conventional method.

### **Best mode for carrying out the invention**

The present invention is to provide porous spherical particles having a polyvinyl acetal resin as a skeleton. Moreover, the present invention is to provide porous spherical particles a spongy polyvinyl acetal resin having a communicating hole as a pore.

Therefore, when polyvinyl acetal porous spherical particles, in particular, porous spherical particles of polyvinyl formal (PVF) are used as a carrier of microorganisms, a microbial carrier excellent in abrasion resistance, weather light-proof, biolysis resistance, flowability, and affinity to microorganisms can be obtained.

Since such porous spherical particles are not hydrate gel structure but spongy porous body having a skeleton structure of polyvinyl acetal, it is excellent in abrasion resistance and mechanical strength compared with those of gel body. Therefore, the porous spherical particles of the present investigation is suitably used for solution holding material and vegetable support material in hydroponics of corps, medium for animal and plant cells, artificial sphagnum, and soil improvement material, a piping washing member, filter

medium, water absorbing material, etc. other than using as a microbial carrier. In addition, as a special example of using the particles, it is also possible to use as an underwater fluid-type-washing member or an underwater fluid-type massage member. Herein, an underwater fluid-type washing member means the washing member for making vegetables contact and washing the surface of vegetables by putting in underwater with a vegetable, generating a bubble from the bottom of a tank, and stirring the whole with a bubble, in order to wash the vegetable with the delicate surface, the vegetable with much convexoconcave, etc. Moreover, the underwater fluid-type massage member provides the massage effect to a human body, which means the member for providing a stimulus to the skin and providing the massage effect by making a human body contact, making said particle flow in tanks, such as a bathtub.

Since the microbial carrier has a affinity for microorganisms and the excellent flowability in particular, it can be used very suitable for the purpose of a fluidized bed type. More particularly, the porous spherical particle of a uniformity particle size near the true sphere which comprises the polyvinyl acetal resin as skeleton is much more superior in the mechanical strength and abrasion resistance, therefore the filling to a container and its flowability as a microbial carrier improve much more.

Moreover, as the process for producing these porous spherical particles, this inventors found out that the porous spherical particle which comprises the polyvinyl acetal resin as skeleton by making the polyvinyl alcohol and the aldehydes in a said droplet react while the solution containing the water soluble polymer, the polyvinyl alcohol and the aldehydes which have the character gelled in an acidic solution is dropped in an acidic solution and a said droplet is made to gel was obtained.

Since the oil droplet of the stock solution forming a particle becomes a particle directly by the contact with a reaction mixture according to this process of producing, the acetalized treatment and the forming process of a spherical particle can be performed at the same time. In addition, because the water soluble polymer gelled when acid which is a catalyst for acetalizing is contacted is included, the form of an oil droplet does not break. Therefore, the porous spherical particle having a uniformity particle size near a true sphere can be produced simply and in a high productivity, without requiring the conventional many steps.



**Best mode for carrying out the invention**

These inventions are porous spherical particles which comprise the polyvinyl acetal resin as skeleton. Moreover, these inventions are the porous spherical particles comprising the spongy polyvinyl acetal resin having a communicating pore as a pore.

The polyvinyl acetal porous spherical particles obtained by the present invention is obtained by reacting polyvinyl alcohol aldehydes. Polyvinyl alcohol used as a raw material, is not particularly limited but preferably a polyvinyl alcohol having an average polymerization degree of 500-3800, and a complete saponification product, or the mixture of the partial saponification product and the low polymerization product. When the average polymerization degree is less than 500, it is difficult to obtain the particle having a high porosity. Whole the average polymerization degree exceeds 3800, as the viscosity becomes too high in time of dissolving in water, thereby handling is difficult in the process of kneading or the like. In addition, polyvinyl alcohol materials whose polymerization degree are different in each other can also be used by blending. There is no problem in using materials outside the above-mentioned range, for example, a material having a polymerization degree of 1500 are mixed with having polymerization 300. In order to obtain in particular regulation of elasticity, flexibility, suitability, and porosity, as well as improvement in water absorptivity, and the like the polyvinyl-alcohol resin having a low polymerization degree may be used.

Although the porosity of this polyvinyl acetal porous spherical particle can be set up depending on the purpose to be used and is not limited in particular, a range of 50 - 98% is preferable. In case above-mentioned porosity is less than 50%, each pore hardly adjoin each other thereby closed-cells tend to occur, and as a result, water is prevented remarkably deteriorated. Whole the porosity exceeds 98%, because mechanical strength such as abrasion resistance decreases the disadvantage that the use is limited in a certain purpose may occur.

The acetalization degree of a polyvinyl acetal porous body is not limited in particular, but those having an acetalization degree of 30-85 % by mol, and preferably an acetalization degree of 45-70 % by mol are suitable. Especially, the polyvinyl formal

having a formalization degree of 30 - 85 % by mol, and preferably a formalization degree of 45 - 70 % by mol are suitable.

By regulating an acetalization degree to the above range, the microbial carrier having flexibility and abrasion resistance can be obtained. In addition, because the cross-linking degree of the molecule is low when an acetalization degree is less than 30 % by mol, the strength is inferior and the fastness to rubbing decreases. Therefore, when it is used in particular as a spherical porous body in a fluidized bed type, it is easy to abrade by the rub of the carriers and the friction with the inner wall of a reaction vessel which are generated at the time of flowing carriers, and, consequently the life span of the carriers decreases. It is also considerable at the point that microbial corrosion resistance decreases. Furthermore, there is also a problem that handling is difficult in the producing process. On the other hand, when an acetalization degree exceeds 85 % by mol, porosity decreases and apparent specific gravity increases, thereby water content decreases. Although it becomes easy to precipitate but it becomes hard to float when it is used as a spherical porous body in a fluidized bed type in particular, therefore the flowability in a processing vessel decreases. More particularly, it is undesirable because a hydrophilic properties decrease with the decrease of the amount of residual hydroxyl groups. As the impact resilience at the time of wetting also decreases, it is undesirable from the viewpoint of the water absorptivity and durability. When a compression press article is produced in particular by the dryness compression process, it is hard but not to be restored to the original form even when it is wetted within a processing vessel etc. Therefore, it is easy to receive a permanent deformation and cannot be a press working. Considering this point, the polyvinyl acetal porous body having an acetalization degree of 30 to 85 % by mol, preferably 45-70 % by mol, and in particular, polyvinyl formal having a formalization degree of 30 to 85 % by mol, preferably 45 - 70 % by mol are preferable in the point of microbial corrosion resistance, and are also excellent in strength, and fastness to rubbing.

Therefore, when it is used in particular as a spherical porous body in a fluidized bed type, the life of a carrier improves. When it uses as a spherical porous body of a fluidized bed type, the suitable porosity easily rising and falling the particles as well as flowing in a processing vessel, and the apparent specific gravity of the hydrate status can be held and the hydrophilic property also favorable thereby excellent flowability is realized. Besides,

the impact resilience at the time of wetting also becomes high, and it is hard to receive a permanent deformation even when it forms a compression press article by the dryness compression process. Further it is wetted in a processing vessel, it is restored to the original form. Therefore, the porous spherical particles of the present invention can form compression porous spherical particles as a press working product, and, thereby, can markedly improve the conveyance ability of a spherical porous. When this particle is wetted in a processing vessel, etc., it fits to a processing solution and restored to the original shape by osmosis the particle can be immediately be made to rise and fall as well as flow in a processing vessel. Therefore, it is not necessary to wait until it becomes a hydrate particle, according to the present processing time can be remarkably shortened. The compressed porous spherical particle means the particle which compressed (pressed) the porous spherical particle according to the present invention in a certain form.

At this point, using a smaller recovery filter, is also considered for example, slit aperture having the wedge wire screen of 1.5mm of apertures installed in the outlet of a processing solution. However, since this slit is blockaded by the attachment as the particulate, the microorganism, and the viscous product of the microorganism source, etc. in drainage, there is also a limit in the aperture of the filter. Therefore, the optimum size of a polyvinyl acetal porous spherical particle is also prescribed from the relation with the recovery filter for the spherical microbial carrier.

The size of the porous spherical particle of the present invention is simply controlled by the size of the droplet dropped as below-mentioned. More specifically, particles having any particle diameters can be obtained by optionally regulating the outlet rate of a droplet, and the aperture of a nozzle required for instillation.

The porous spherical particle of the present invention has many pores whose pore diameter is 20-300 micrometers which is the size that which water and air can come and go freely, therefore it differs from the mere gel having a network structure in a molecule level. When used within a flow vessel as a microbial carrier, the organic substance, the phosphorus or the nitrogen compound in water etc. goes in and out freely through the pore of this size, and becomes easy to spread. Moreover, since the film by the microorganism is easy to be formed and the microorganism film formed on the carrier surface hardly exfoliates, the microbial carrier having many pores of the pore diameter of 20-300 $\mu$ m is

suitable. The pore diameter may be partly controlled by using the below-mentioned process of producing.

A sponge comprising the porous spherical particle according to the present invention has many pores of the size that water and air may go in and out freely, in the same way, and has the moderate elasticity of about  $2-200 \times 10^3 \text{N/m}^2$  in 50% compressional stress in the status that 50% of moisture contents swelled with water. This moderate elasticity exhibits favorable abrasion resistance at the time of the flow of the carrier.

Moreover, in order to raise the abrasion resistance and the mechanical strength of this porous spherical particle, it is desirable to form the coat having pores in the particle surface, and a vesicular structure inside of a particle. The spherical particle prepared by the below-mentioned process of producing of the present invention is excellent in the mechanical strength with the coat coated on the surface.

In cases where the porous spherical particle of the present invention is only supplied to the processing vessel of a fluidized bed type, it flows in the processing vessel as a hydrated porous body, rising and falling favorably by the aeration etc. In addition, the affinity for microorganisms is favorable in material. Therefore, a microorganism adheres to it and the excellent organism treatment may be performed. On the one hand, since the abrasion resistance of the particle of the present invention is also favorable, it is hardly abraded out by the rub of the carriers and the rub with the inside wall of the reaction vessel which are generated at the time of flowing the carrier. Furthermore, since it has high mechanical strength, and excellent weatherlight-proof, and excellent biolysis resistance by the microorganism, the life of the carrier becomes long.

The porous spherical particle of the present having a polyvinyl acetal resin invention as skeleton is also excellent as the microbial carrier.

As mentioned previously, the above-mentioned microbial carrier is suitable for attaching the microorganism on the surface of a carrier comprising the inside of a pore of a porous body. Since the particle carrier is also excellent in flowability, it is suitable for a fluidized bed type. However, applying the carrier as a comprehensive immobilized microorganism method with an above-mentioned microorganism film method is desired, for the following reasons of a comprehensive immobilized microorganism method: 1) A microorganism may be maintained at high concentration and the operation of the wastewater treatment

may be performed at high speed; 2) By immobilizing a specific microorganism, processing of the specific material or the recovery of an organic substance are possible; 3) The generation rate of sludge can be reduced. Accordingly, the microbial carrier by which the microorganism was positively immobilized in the pore of a porous body with the microorganism-immobilizing agent was developed.

Thereby, while the carrier is excellent in abrasion resistance, weatherlight-proof, biolysis resistance by the microorganism, flowability, and an affinity for microorganisms, a microorganism is maintained at high concentration and the operation of the wastewater treatment is performed at high speed. Furthermore, since processing of the specific material and a recovery of a valuable are attained by immobilizing a specific microorganism, the generation rate of sludge can be reduced. That is, the microbial carrier which efficiently employs the advantage of the microorganism film method and the comprehensive immobilized microorganism method, respectively, and further conquers the fault of both microorganism film method and comprehensive immobilized microorganism method can be obtained.

Herein, although various microorganism-immobilizing agents can be used and are not limited particularly, the microorganism-immobilizing agent whose sodium alginate is an essential ingredient is preferable. When a sodium alginate is an essential ingredient, it is easy to perform filling and immobilizing favorably to a polyvinyl acetal porous spherical particle, in particular, a polyvinyl formal porous spherical particle, and is compatible. It is also in particular favorable in respect of abrasion resistance.

The comprehensive immobilization of microorganism using the microorganism immobilizing agent can be achieved by for example, allowing a porous spherical particle to permeate the mixed solution of the microorganism immobilizing agent containing microorganisms, and insolubilizing the above-mentioned microorganism immobilizing agent in the pore of the above-mentioned porous body.

The microbial carrier of the present invention is applied in any of a aforementioned comprehensive immobilizing type (comprehensive immobilization method) and the above-mentioned un-comprehensive immobilizing type (microorganism film method), and it may be also applied as the carrier in any of a fluidized bed and a fixed bed as mentioned previously. It is also applied in the purpose of various kinds of bioreactors containing

swage-disposal apparatus.

In particular, the microbial carrier of the present invention can be suitably used as fluidized-bed-type swage-disposal apparatus treated by rising and falling and circulating the spherical microbial carrier of the present invention in a processing vessel.

For example, the bioreactor of a fluidized-bed type can be applied which performs organism processing and chemical preparation by contacting the carrier with treated solution. More specifically, it is applicable to apparatus with which chemical reactions, such as the oxidation reduction such as nitrification denitrification, addition, substitution, transformation, desorption, besides decomposition of an organic substance etc., are performed.

The porous spherical particles of the present invention are preferably compression press moldings as aforementioned. Particularly, it is the sponge spherical body of 10% or less of moisture contents. The suitable particle is a polyvinyl acetal porous spherical particle, characterized by that the volume expands 2 to 10 times quickly, and the size in moisture status is 1mm - 20mm, when supplied in water.

The compressive porous spherical particle (it writes briefly as a compressive particle in the following) by which the compression press of the porous spherical particle of the present invention having a polyvinyl acetal resin as skeleton was carried out can be produced by a compression process and a dryness process. When such a compressive particle is supplied to a processing vessel as a microbial carrier, while it is quickly restored to original shape and original size by the imbibition, it permeates in a processing solution by a wetting, and soon, it may rise and fall and flow. On the other hand, the porous spherical particle without a compression press will be floated on the water surface for the reason for being hard to leave air incorporated in the particle, and as a result, it requires time until a flow becomes possible. The cost of conveyance becomes remarkably cheap as above-mentioned because the volume of a porous body is reduced by the compression press.

As for the process of the compression press herein, it is preferable to carry out an operation after a dryness process. Even if a compression press is carried out in a moisture state, it will return soon. When the operation of the compression press in the status that the moisture content was dried to 10% or less is carried out to the polyvinyl acetal porous

spherical particle produced in suitable conditions, long-term conservation in the compressed status is possible. Moreover, when the particle is supplied in water, it expands quickly, and is restored to original shape and original size.

The high compressibility is suitable and  $1/2-1/10$  are preferable. In case the compressive particle compressed to  $1/2-1/10$  is supplied in water, it expands to 2-10 times quickly, and is restored to an original size and original shape. As for the size in the moisture status of porous spherical particle, in the use as a microbial carrier, it is preferable that it is 1-20mm because of an above-mentioned reason.

In addition, when the use immediately after input into the processing vessel is desired much more, the polyvinyl acetal porous spherical particle in a moisture status is preferable.

Such a porous spherical particle is used suitable for the carrier for enzyme fixation, solution holding material and vegetable support material for the hydroponics of agricultural products, medium for animals and plants cell, artificial sphagnum, and soil improvement material, etc. besides the purpose as a microbial carrier. In addition, as a special example of use, it is also possible to use as an underwater fluid-type washing member or an underwater fluid-type massage member.

In order to form a comprehensive immobilized-microorganism carrier using this porous spherical particle, the porous spherical particle can be immobilized by supplying to the liquid distributed the activated sludge and allowing a microorganism to adhere on the surface of an above-mentioned porous spherical particle and/or in a pore. Moreover, for example, when using a microorganism-immobilizing agent for the immobilization of microorganisms, the immobilizing agent is dispersed in an activated sludge, and the porous spherical particle is supplied and immobilized in it. In this case, when a compressive particle is used, sludge permeates to the inside of a particle quickly, and it is suitable for it.

Particularly, in use of the sodium alginate as a immobilizing agent, the porous microbial carrier of the particle shape which immobilized the above-mentioned microorganism comprehensively can be obtained by allowing the microbial carrier of the above-mentioned porous spherical particle to permeate the mixed solution of the sodium alginate containing microorganisms, adding polyvalent metal salt water solutions, such as a calcium chloride aqueous solution, to the microbial carrier which permeated the mixed solution of this

sodium alginate, and insolubilizing an above-mentioned sodium alginate on the surface of the above-mentioned porous body and /or in a pore. In addition, as for influxing the microorganism-immobilizing agent the influx into the pore of the microbial carrier, it is desirable to carry out an operation under a reduced pressure.

The microbial carrier of the porous spherical particle of the present invention is suitable for any well-known microorganism treatment apparatus, and can be used by being filled to a microorganism-treatment vessel in a single vessel type and a multi-vessels type. It also acts effectively in any of anaerobic treatment and an aerobic treatment. The microbial carrier of the present invention is also suitable as a carrier used not only a fluid-bed but the so-called fixed bed type immobilized the carrier inside the reaction vessel.

The above-mentioned porous spherical particle can be produced simply and in a high productivity by the following process of producing.

As one of process for producing, the process for producing the porous spherical particle characterized by obtaining the porous spherical particle having a polyvinyl acetal resin as a skeleton by dropping the water soluble polymer with gelling property in an acidic solution and the aqueous solution obtained by mixing of polyvinyl alcohol with aldehydes into the acidic solution for the gelation of said droplet, and allowing the polyvinyl alcohol to react with the aldehydes in said droplet at the same time.

According to this process of producing, since the acetalized treatment, and the forming process of a spherical particle can be performed at the same time, the porous spherical particle having a uniformity particle size near a true sphere can be produced simply and in a high productivity, without requiring the conventional many steps. Furthermore, since the coating is given on the surface of the particle, it excels in the mechanical strength.

This process of producing is characterized by allowing the solution containing polyvinyl alcohol to react with an acidic solution and preparing droplet- shape, and starting acetalization of polyvinyl alcohol and aldehydes included in this droplet through the effect of the acidic solution as a catalyst at the same time. That is, polyvinyl alcohol and aldehydes in that solution maintains the status of a solution, without causing a reaction, while not contacting the acidic solution as a catalyst. However, an acetalized reaction is started at the time when it contacts the acidic solution, and solidification starts. Moreover, since the water soluble polymer with gelling property in the acidic solution containing in



the solution, for example, water soluble polymer with the characteristic capable of gelling by ion exchange reaction, changes to gel material through ion exchange etc. immediately by the effect of acid and produces viscosity, it plays the role for preventing the deformation of the spherical form for the reaction of a polyvinyl alcohol and aldehydes. In the process for producing of the present invention, it is also possible to obtain a comprehensive immobilized carrier by mixing microorganisms in the aqueous solution comprising polyvinyl alcohol, water soluble polymer, and aldehydes, and, therefore, required treatment, such as regulation of the blending corresponding to the use purpose, can also be performed.

That the particle obtained by this method is porosity arises from the reason apertures are formed by drying and shrinking of gel, such as calcium alginate which is present in the particle comprising polyvinyl acetal skeleton particle, with drying of this spherical particle. Moreover, it is considered that the reason a coating is formed on the particle surface since the material (both of pore forming agents, such as the water-soluble-polymer gel and a starch) which acts as a pore forming agent cannot exist on the surface is so that skeleton formation process the same as at the time of the reaction of with aldehydes within the particle which a pore forming agent exists abundantly cannot be taken. Consequently, on the particle surface of the present invention on which an acetalized reaction is performed in the form of a spherical particle, while a porous spherical particle comprises the particle with which the thin film having a pore on the surface was coated on the particle surface, the inside of a particle comprises the porous body having the spongy three-dimensional network structure of high porosity.

The water soluble polymer (ditto for other following process for producing) with the characteristic capable of gelling through ion exchange reaction etc. in an acidic solution is not particularly limited, and includes sodium arginine, carrageenan, and sodium polyacrylate.

Concentration of polyvinyl alcohol is not limited in particular. Generally, when polyvinylalcohol concentration is high, the spherical particle is easy to be obtained, and when polyvinyl alcohol concentration is low, the hydrated gel particle is easy to be obtained. The difference in the physical property of these particles is not necessarily dependent only on polyvinyl alcohol concentration, and is influenced by other factors.

However, in a spherical particle, polyvinyl alcohol concentration is the important main component in obtaining the particle of the resin skeleton which is not a hydrated gel particle. Therefore, in the present invention, the amount of the compounding is important. When polyvinyl alcohol concentration exceeds 20 % of the weight by the present invention, since handling is not only difficult by the viscosity of the very high solution, but the particle of the drop shape where yarn was pulled at the time of a dropping is generated, the spherical particle with the uniformity diameter or near a uniformity diameter is hard to be obtained. Since the strength of the spherical particle obtained by the acetalized reaction after dropping decreases when polyvinyl-alcohol concentration is less than 5 wt%, it is not preferable. Therefore, preferable polyvinyl-alcohol concentration is 5 - 20wt%. In particular, 7 - 15wt% is the most preferable. However, when producing a hollow particle in the process of producing described in the below-mentioned claim 20, a beautiful particle is easy to be obtained by performing it at somewhat low concentration. In particular, about 1-7wt% is suitable. The temperature of this mixed liquor is not limited in the range in particular. The temperature which can maintain flowability, without denaturalizing to each other is suitable. Ordinary temperature is also satisfactory.

Aldehydes include, for example, fatty series and aromatic series aldehydes, such as formaldehyde, the benzaldehyde, an acetaldehyde, butyraldehyde, acrylaldehyde, or the glyoxal. The acetal which is also transformed into an aldehyde easily by coexistent acid may be used. However, in particular formaldehyde is excellent from viewpoints, such as the reactivity with a polyvinyl alcohol, water soluble, price, operativity, the strength of a resultant, impact resilience, and the ease of the treatment after a reaction.

Concentration of aldehydes is not limited in particular, but, since it affects the degree of acetalization of a resin skeleton particle, it is important. Suitability concentration of the aldehyde in the present invention needs to be suitably selected based on concentration of the coexistent acid catalyst and reaction temperature. Although the arrival time to a desired degree of acetalization can be shortened as aldehyde concentration becomes high, since the rate of reaction will become fast when the concentration is too high, control of the degree of acetalization is difficult. Generally the strength of one of a high degree of acetalization improves. However, when the degree is too high not much, in production of a porous body, while the porosity decreases, apparent specific gravity increases, and, as a result, a water

content decreases. On the one hand, the hydrophilic property decreases with the decrease of the residual hydroxyl group. The impact resilience of the particle is also decreased.

The range of 30-85 % by mol is suitable for the degree of acetalization as above-mentioned. In particular, in order to use suitably as a microbial carrier for the fluidized bed types for which a rubber like elasticity and a comparatively solidity are required, it needs to be set as 55 - 85 % by mol. Although concentration of the aldehydes in this case varies with types, it is preferably set as about 3-10wt% for use of formaldehyde.

The water soluble polymer with the property of gelling in an acidic solution, for example, the water soluble polymer with the property of gelling by the ion exchange reaction, is not limited in particular as mentioned above, and sodium arginine, carrageenan, sodium polyacrylate, etc. are included. The sodium arginine is most excellent from the viewpoint of the speed of a gelation velocity, the gel status, etc., and use of this water soluble polymer is preferable. Although the molecular weight of a sodium arginine is not limited in particular, when one of high molecular weight is used, a gelation velocity will become fast and it will tend to produce a beautiful particle. However, in use of too much high molecular weight, as the viscosity of the solution rises excessively and a drop-like particle is easy to be produced, it is not preferable. In particular, for example, use of the sodium arginine having the viscosity of about 30dPa sec at 20°C, 4% concentration is

Here, a water-soluble polymer having a gelling property, for example, through an ion exchange reaction, contained in the polyvinyl alcohol solution, serves as a pore forming agent and a shape retaining agent, as described earlier; and from this point of view, the concentration thereof is not particularly limited. In general, when the concentration thereof is high, the solution comes to have a high viscosity, and tends to cause a problem in its dropping process. In contrast, when the concentration thereof is low, the reaction rate of the gel formation becomes low, and makes it difficult to obtain spherical particles. Taking account of these characteristics in handling, although it depends on the molecular weight of sodium alginate, in the molecular weight within the above-mentioned range, the concentration is preferably set in the range of 0.5 to 5 weight %, and more preferably, 1 to 5 weight %. In the case of the concentration of sodium alginate less than 0.5 weight %, the dispersing force of the water-soluble polymer itself on the water surface or in water becomes greater than the surface tension thereof, with the result that it fails to hold water

and is dispersed on the water surface. In contrast, when the concentration of sodium alginate exceeds 5 weight %, it is injected from the supply opening in a continuously flowing manner, with the result that it becomes difficult to obtain spherical particles having a uniform particle size.

In the present invention which intends to accelerate the reaction between polyvinyl alcohol and aldehydes, it is preferable to use an acidic solution in the preparation process. With respect to these acids, although not particularly limited, either an inorganic acid, such as sulfuric acid, hydrochloric acid, phosphoric acid or maleic acid, or an organic acid may be used; and among these, strong acids are more preferably used. In particular, sulfuric acid is optimal in its ease in handling; however, it is necessary to properly select the kind of acids to be used depending on the kind of multivalent metal salts to be used in combination.

With respect to the multivalent metal salt aqueous solution, although not particularly limited, mainly calcium chloride, zinc chloride, aluminum sulfate, etc. are preferably used. The concentration is changed depending on kinds of metal salts to be selected and the temperature of the aqueous solution; however, in the case of the application of calcium chloride, it is preferably set in the range of 1 to 20 weight %. Moreover, in the invention of claim 20, if the concentration is too high, the resulting gel particles become too great, and tend to be fused to adhere to other adjacent particles, which raises another problem. Furthermore, in the preparation method of claim 17, when a small amount of a multivalent metal salt such as calcium chloride is added to the acidic aqueous solution, it is possible to prevent the spherical particles from collapsing, and consequently to manufacture spherical particles having a uniform particle size.

In the case of the polyvinyl acetal based spherical particles manufactured by the manufacturing method in accordance with any one of claims 17 to 20, they are obtained not in a state where the polyvinyl acetal is contained in the moisture gel of the water-soluble polymer, but in a state where the moisture gel of the water-soluble polymer such as sodium alginate is contained in the skeleton of the polyvinyl acetal resin. Then, as described earlier, in these resin particles after having been dried, the gel of the water-soluble polymer such as sodium alginate is allowed to shrink, thereby forming a porous material having a fine pore size. Thus, it is possible to obtain porous spherical

resin particles which have elasticity like rubber or is comparatively hard. Moreover, when put into water, the shrunk gel of the water-soluble polymer such as sodium alginate is almost restored as a moisture gel, which has a porous structure utilized as a culture medium for microorganisms. Here, when the gel contained in the particles is eliminated, porous spherical particles with external openings are obtained. When an attempt is made to manufacture particles having a greater pore size and porosity, a pore-forming agent such as starch is preliminarily added to the polyvinyl alcohol solution, as will be described later. The greater pore size and porosity make it possible to easily remove residual materials after the reaction of acetal, and also to shorten washing time. Moreover, the improvement of the porosity allows the apparent specific gravity to decrease, thereby improving the fluidity in water.

Moreover, in another embodiment of the manufacturing method of spherical particles of the present invention, a water solution, which is formed by mixing and dissolving a water-soluble polymer having a gelling property upon ion-exchange reaction and polyvinyl alcohol, is dropped into a multivalent metal salt aqueous solution so that the droplets are allowed to gel via the ion-exchange reaction to form gelled spherical particles. Then, the gelled particles are added to an acidic solution containing aldehyde so that polyvinyl alcohol contained in the gelled particles is allowed to react with aldehydes; thus, it is possible to obtain porous spherical particles having polyvinyl acetal resin having a degree of acetalization of 30 to 85 mole % as their skeleton.

In this manufacturing method, the moisture gel of the water-soluble polymer is not used as the main component of the spherical particles, but utilized as a shape-forming means for the spherical particles so that it becomes possible to easily manufacture a large amount of spherical particles having a polyvinyl acetal-based skeleton with a particle size as uniform as possible. In other words, the ratio of blend between polyvinyl alcohol forming a main component for skeleton particles forming polyvinyl acetal and the water-soluble polymer such as sodium alginate exerting the shape-retaining function and the pore-forming function for the spherical particles in the manufacturing process and the degree of acetalization of polyvinyl alcohol are adjusted to the above-mentioned ratio of blend so that it becomes possible to easily manufacture a large amount of spherical particles having a polyvinyl acetal-based skeleton, which have properties such as rubber elasticity and

comparatively high hardness and a particle shape close to a true globe with a uniform particle size. Moreover, since the acetalization process is prepared as a different process, as compared with the method in accordance with claim 17, etc., this method is more preferable since the adjustment for the degree of acetalization is easily carried out. The adjustment for the degree of acetalization is made by controlling the amount of blend of aldehydes in the reaction solution, the temperature of the reaction solution and the reaction time.

In the method disclosed in claim 20, that is, the method for manufacturing porous spherical particles having a hollow shape having a polyvinyl acetal resin as their skeleton, which are superior in abrasion resistance and mechanical strength, a multivalent metal salt aqueous solution is dropped into an aqueous solution formed by mixing and dissolving a water-soluble polymer having a gelling property upon ion-exchange reaction and polyvinyl alcohol; thus, aggregation is formed by the reaction between the droplets of the multivalent metal salt and the water-soluble polymer, with the result that gelled spherical particles, which mixedly have the gel of the water-soluble polymer reacted with the multivalent metal salt and polyvinyl alcohol, are formed on the periphery of each droplet. Thereafter, the gelled particles is added to an acidic aqueous solution containing aldehydes so that polyvinyl alcohol contained in the gelled particles is allowed to react with the aldehydes so as to obtain a target product.

In the manufacturing method of the present invention, the multivalent metal salt aqueous solution is dropped into the polyvinyl alcohol solution so that the peripheral portion of each droplet is allowed to gel with the result that since the polyvinyl alcohol solution is not allowed to enter the inside of the droplet, no gelation occurs and the resulting product is provided as hollow particles.

The reason that spherical particles obtained by the above-mentioned manufacturing methods form porous shapes is because, as described earlier, the gel located inside the polyvinyl acetal based skeleton particles is allowed to shrink. However, in the case when pores having a greater size are required or the distribution of the porosity between the outer face and inner face of the particles is removed, a pore-forming agent is added to an aqueous solution formed by mixing and dissolving at least polyvinyl alcohol and a water-soluble polymer having a property of gelling via an ion exchange reaction so that it

is possible to manufacture a porous material having a large pore size. With respect to the pore-forming agent, although not particularly limited, starch is most preferably used since the grain size is comparatively uniform, and the size of particles is suitable for the size of pores that is required for the porous spherical particles of the present invention. Moreover, starch is easily washed away with water at the time of washing the porous spherical particles, making it possible to easily handle the resulting particles. When manufactured by adding the pore-forming agent such as starch, the porous spherical particles are more preferably utilized as microbial carriers of, in particular, fluidized bed type.

Moreover, it is possible to positively remove the gel from the porous spherical particles having the polyvinyl acetal resin as their skeleton. In other words, the above-mentioned porous spherical particles form the porous material with the gel being shrunk due to drying; however, when the porous spherical particles are moistened, the gel is restored with their porous structure being maintained. Therefore, by positively removing the gel, the porous material having external openings in a moistened state is prepared.

The main component of the gel is a water-soluble polymer having a property of gelling by an acidic solution. With respect to a method for removing the water-soluble polymer such as alginic acid, examples thereof include a method in which the particles are added to a solution containing sodium ions and stirred and washed so as to subject them to an ion exchange reaction, a method in which a chelating agent to calcium ions, such as ethylenediamine tetraacetate (EDTA) and a phosphate acid buffer, is utilized and a method in which a centrifugal separation is utilized. Either of these provides a preferable gel removing method.

Here, the pore size, the porosity and the degree of acetalization in the present invention including the following examples were obtained based upon the following measuring method.

(Measurements on pore size)

The pore size was measured based upon ASTM (Designation: D4404-84). Specifically, the average pore size was found by using a porosimeter made by POROUS MATERIALS, INC CO., Ltd. through a mercury-press-in pore measuring method.

(Measurements on porosity)

Samples in a wet state were measured in their diameters by using calipers at three portions so as to obtain the apparent volume (Va) and also measured by using an automatic dry-type densitometer Acupic 1330 (trade name) made by Shimadzu Seisakusho K.K. so as to obtain the true volume (V). Based upon these values, the porosity.(%) was calculated through the following equation:

$$\varepsilon = (1 - V_a / V) \times 100$$

(Measurements on acetalization)

The degree of acetalization F (%) was calculated from the following equation based upon proton NMR measurements in a chloroform deuteride, trifluoroacetate aqueous solution.

$$F = (a / c) \times 100$$

c: Total peak intensities of methine protons (for example, 4.153, 4.442 ppm)

a: Total of peak intensities of methylene protons (for example, 4.667, 5.150, 5.313, 5.326 ppm) adjacent to an ether group

The following description will discuss the present invention in detail by means of examples. However, the present invention is not intended to be limited by these examples. Here, in the following examples and comparative examples, "%" refers to "weight %".

#### (Example 1)

##### (Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Formaldehyde      | 4.0 %  |
| Water             | 87.5 % |

##### (Reaction solution)

|               |        |
|---------------|--------|
| Sulfuric acid | 10.0 % |
| Water         | 90.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled and combined with an aqueous solution of sodium alginate which was prepared separately and further with an



aqueous solution of formaldehyde, and then mixed uniformly. The solution mixture thus obtained was then added dropwise to a 10 % aqueous solution of sulfuric acid. The temperature of this aqueous solution of sulfuric acid was 60°C. A droplet formed in the aqueous solution of sulfuric acid gelled within about 5 minutes and allowed to be reacted in situ for about 15 minutes and then this particle was separated to yield a elastic particle whose resin backbone (skeleton) was a polyvinyl acetal. This particle was washed thoroughly with water and dried to yield a polyvinyl acetal-based porous spherical particle whose particle size was 3 to 4 mm and which was close to a true sphere having a uniform diameter.

(Example 2)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Water             | 91.5 % |

(Reaction solution)

|               |        |
|---------------|--------|
| Sulfuric acid | 5.0 %  |
| Formaldehyde  | 4.0 %  |
| Water         | 91.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled and combined with an aqueous solution of sodium alginate which was prepared separately. This solution mixture was added dropwise to a solution prepared separately by mixing an aqueous solution of formaldehyde and an aqueous solution of a sulfuric acid uniformly. A droplet that was dripped gelled within about 5 minutes and allowed to be reacted in situ for about 30 minutes to yield an elastic particle whose resin backbone was a polyvinyl acetal. This particle was almost similar to that obtained in Example 1.

(Comparative 1)

(Drop solution)

|                   |       |
|-------------------|-------|
| Polyvinyl alcohol | 7.5 % |
|-------------------|-------|

|                     |        |
|---------------------|--------|
| Formaldehyde        | 4.0 %  |
| Water               | 89.5 % |
| (Reaction solution) |        |
| Sulfuric acid       | 10.0 % |
| Water               | 90.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled and combined with an aqueous solution of formaldehyde and mixed uniformly. Then this solution mixture was added dropwise to a 10 % aqueous solution of sulfuric acid at 60°C. However, the solution mixture dripped was not present as a droplet and dispersed gradually in the acidic aqueous solution with allowing the reaction to take place at the same time to yield a solid which was just like a cloud, resulting in no production of a spherical particle.

(Comparative 2)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 8.0 %  |
| Water             | 92.0 % |

(Reaction solution)

|               |        |
|---------------|--------|
| Sulfuric acid | 5.0 %  |
| Formaldehyde  | 4.0 %  |
| Water         | 91.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled. This solution mixture was added dropwise to a solution prepared separately by mixing an aqueous solution of formaldehyde and an aqueous solution of a sulfuric acid uniformly. This acidic aqueous solution of formalin was 60°C. However, no spherical particle was obtained due to the event similar to that in Comparative 1.

(Example 3)

(Drop solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 2.0 %  |
| Water            | 98.0 % |

(1st Reaction solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 3.0 %  |
| Sodium alginate   | 0.5 %  |
| Water             | 96.5 % |

(2nd Reaction solution)

|               |        |
|---------------|--------|
| Formaldehyde  | 8.0 %  |
| Sulfuric acid | 10.0 % |
| Water         | 91.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled, and combined with an aqueous solution of sodium alginate prepared separately to form 2000 ml in total of a

solution mixture. The temperature of this solution mixture was room temperature. When this solution was treated dropwise slowly with an aqueous solution of calcium chloride, a droplet began to be solidified and gelled completely after about 5 minutes to yield a semi-transparent spherical particle. Subsequently, this gel particle was isolated and added to a solution mixture of formalin and sulfuric acid at 60°C. Upon addition, the semi-transparent gel particle began to be turbid, and then turned into white completely after about 10 minutes, yielding a spherical particle whose resin backbone was a polyvinyl acetal and which has a rubber elasticity. This was washed thoroughly with water to obtain a polyvinyl acetal-based hollow particle whose particle size was 3 to 4 mm and which was close to a true sphere having a uniform diameter.

(Comparative 3)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Calcium chloride  | 5.0 %  |
| Water             | 87.5 % |

(1st Reaction solution)

|                 |        |
|-----------------|--------|
| Sodium alginate | 0.5 %  |
| Water           | 99.5 % |

(2nd Reaction solution)

|               |        |
|---------------|--------|
| Formaldehyde  | 8.0 %  |
| Sulfuric acid | 10.0 % |
| Water         | 82.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled, and combined with an aqueous solution of calcium chloride prepared separately to form 2000 ml in total of a solution mixture. When this solution was added dropwise slowly to an aqueous solution of sodium alginate, the solution gelled with being sedimented to form a semi-transparent ribbon-like gel. This ribbon-like gel was isolated and added to an aqueous solution mixture of formalin and sulfuric acid at 60°C. Upon addition, the semi-transparent gel particle began to be turbid, and then turned into white completely after about 10 minutes,

yielding an article which had a rubber elasticity but was not a spherical particle and was not hollow.

(Comparative 4)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 5.0 %  |
| Calcium chloride  | 2.0 %  |
| Formaldehyde      | 3.0 %  |
| Sulfuric acid     | 4.0 %  |
| Water             | 86.0 % |

(1st Reaction solution)

|                 |        |
|-----------------|--------|
| Sodium alginate | 0.5 %  |
| Water           | 96.5 % |

(2nd Reaction solution)

|       |        |
|-------|--------|
| Water | 82.0 % |
|-------|--------|

A solution mixture consisting of a polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely, formaldehyde and sulfuric acid was added dropwise slowly to an aqueous solution of sodium alginate, and gelled with being sedimented. This particle was separated and added to a water bath at 60°C to react for 30 minutes to obtain an elastic particle. However, the particle was not hollows and was poorer in terms of the strength when compared with the particle obtained in Example 3. The remainder of the solution which was not added dropwise was solidified in 15 minutes, revealing that the drop solution should have been consumed within a short period after preparation.

(Example 4)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Water             | 91.5 % |

(1st Reaction solution)

|                         |        |
|-------------------------|--------|
| Calcium chloride        | 3.0 %  |
| Water                   | 97.0 % |
| (2nd Reaction solution) |        |
| Formaldehyde            | 3.0 %  |
| Sulfuric acid           | 4.0 %  |
| Water                   | 93.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled, and combined with an aqueous solution of sodium alginate prepared separately to form 2000 ml in total of a solution mixture. When this solution was added dropwise slowly to 5000 ml of an aqueous solution of calcium chloride, a droplet began to be solidified immediately and lost the fluidity, and then gelled completely after about 3 minutes to form a semi-transparent spherical particle. Subsequently, this gel particle was isolated and added to an aqueous solution mixture of 4% formaldehyde and 5% sulfuric acid. Upon addition, the semi-transparent gel particle began to be turbid, and then turned into white completely after about 3 minutes, yielding a spherical particle having a rubber elasticity. This was washed thoroughly with water to obtain a polyvinyl acetal-based porous spherical particle whose particle size was 3 to 4 mm and which was close to a true sphere having a uniform diameter. This spherical particle was dried and examined for its internal structure using a scanning electron microscope, which revealed that it had a large number of pores of 2 to 4 $\mu$ m in each diameter, which were all continuous pores.

(Example 5)

(Drop solution)

|                         |        |
|-------------------------|--------|
| Polyvinyl alcohol       | 7.5 %  |
| Sodium alginate         | 1.0 %  |
| Water                   | 91.5 % |
| (1st Reaction solution) |        |
| Calcium chloride        | 3.0 %  |
| Water                   | 97.0 % |

**(2nd Reaction solution)**

|               |        |
|---------------|--------|
| Formaldehyde  | 8.0 %  |
| Sulfuric acid | 10.0 % |
| Water         | 82.0 % |

A gel particle was obtained similarly to Example 4 and then isolated and added to an aqueous solution mixture of 8% formaldehyde and 10% sulfuric acid at 80°C. After it was allowed to react in this condition, a non-elastic spherical particle having a diameter of 3 to 4 mm was obtained. This spherical particle had a fine crater-like protrusion and recess. This was washed thoroughly with water and dried, and then examined for its internal structure using a scanning electron microscope, which revealed that it had a large number of pores of 2 to 4 $\mu$ m in each diameter, which were all continuous pores.

(Example 6)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Water             | 91.5 % |

(1st Reaction solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 3.0 %  |
| Water            | 97.0 % |

(2nd Reaction solution)

|               |        |
|---------------|--------|
| Formaldehyde  | 8.0 %  |
| Sulfuric acid | 10.0 % |
| Water         | 93.0 % |

Similarly to Example 5, a gel particle was added to an aqueous solution mixture of 8 % formaldehyde and 10 % sulfuric acid at 20°C and allowed to react for 15 hours, whereby yielding a rigid spherical particle similar to that in Example 2, whose surface was smoother than that obtained in Example 5.

(Example 7)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Corn starch       | 5.0 %  |
| Water             | 86.5 % |

(1st Reaction solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 3.0 %  |
| Water            | 97.0 % |

(2nd Reaction solution)

|               |        |
|---------------|--------|
| Formaldehyde  | 10.0 % |
| Sulfuric acid | 15.0 % |
| Water         | 75.0 % |



When a solution mixture prepared similarly to Example 4 was added dropwise to 5000 ml of an aqueous solution of calcium chloride at 70°C, it began to be solidified and then gelled completely after 15 minutes to yield a semi-transparent elastic particle. Subsequently, this gel particle was added to an aqueous solution containing formaldehyde and sulfuric acid at 60°C and allowed to react for about 60 minutes to yield a white spherical particle. When this particle was stirred in this condition, it was readily fluidized, and exhibited a higher fluidity when compared with that obtained in Example 4. The degree of acetalization of the spherical particle obtained in this example was about 67% by mole.

(Example 8)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Corn starch       | 5.0 %  |
| Water             | 86.5 % |

(1st Reaction solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 3.0 %  |
| Water            | 97.0 % |

(2nd Reaction solution)

|               |        |
|---------------|--------|
| Formaldehyde  | 10.0 % |
| Sulfuric acid | 15.0 % |
| Water         | 75.0 % |

When a solution mixture prepared similarly to Example 4 was added dropwise to 5000 ml of an aqueous solution of calcium chloride at 70°C, it began to be solidified and then gelled completely after 15 minutes to yield a semi-transparent elastic particle. Subsequently, this gel particle was added to an aqueous solution containing formaldehyde and sulfuric acid at 75°C and allowed to react for about 15 minutes to yield a white spherical particle. When this particle was stirred in this condition, it was readily fluidized,

and exhibited a higher fluidity when compared with that obtained in Example 4. The degree of acetalization of the spherical particle obtained in this example was about 65 % by mole.

(Comparative 5)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 10.0 % |
| Sodium alginate   | 1.0 %  |
| Water             | 89.0 % |

(Reaction solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 3.0 %  |
| Water            | 97.0 % |

A polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified completely was dissolved in a hot water and then cooled, and combined with an aqueous solution of sodium alginate prepared separately to form 2000 ml in total of a solution mixture. When this solution was added dropwise slowly to 5000 ml of a 3 % aqueous solution of calcium chloride, a droplet began to be solidified immediately and lost the fluidity, and then gelled completely after about 3 minutes, but the particle had a droplet-like shape instead of a true sphere.

(Comparative 6)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 8.0 %  |
| Water             | 92.0 % |

(Reaction solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 3.0 %  |
| Water            | 97.0 % |

When a 8 % aqueous solution of a polyvinyl alcohol resin whose mean polymerization degree was 1500 and which was saponified dissolved in water was added dropwise

slowly to 5000 ml of a 3 % aqueous solution of calcium chloride, a droplet was dispersed over the surface of the aqueous solution of calcium chloride, and this solution was not solidified even after being allowed to stand in this condition for 10 minutes, yielding no gel material.

(Comparative 7)

(Drop solution)

|                   |        |
|-------------------|--------|
| Polyvinyl alcohol | 7.5 %  |
| Sodium alginate   | 1.0 %  |
| Corn starch       | 5.0 %  |
| Water             | 86.5 % |

(1st Reaction solution)

|                  |        |
|------------------|--------|
| Calcium chloride | 3.0 %  |
| Water            | 97.0 % |

(2nd Reaction solution)

|               |        |
|---------------|--------|
| Formaldehyde  | 10.0 % |
| Sulfuric acid | 15.0 % |
| Water         | 75.0 % |

When the mixed solution, prepared in the same process as Example 4, was dropped into 5000 ml of a calcium chloride aqueous solution at 70°C, the solution started to solidify, and 15 minutes later, this was completely allowed to gel to obtain translucent elastic particles. Next, these gelled particles were added to an aqueous solution containing formaldehyde and sulfuric acid at 60°C, and this was allowed to react for 15 minutes to obtain white spherical particles. When this was stirred in this state, the particles were easily fluidized, and exhibited a high fluidity even as compared with those obtained in Example 4. However, the degree of acetalization of the spherical particles obtained in the present Comparative Example was approximately 30% by mol, and the susceptibility to abrasion was confirmed in a durability test, which will be described later.

The spherical particles, obtained in the respective examples, were sponge-shaped particles with continuous bubbles, which have a mesh structure, and they have a superior

hydrophilic property and are superior in flexibility and elasticity in a wet state. Among these porous materials, 10 of them were selected as samples, and subjected to measurements on various properties. The results showed that the porosity was uniformly dispersed in the range of 80 to 95%, and the average porosity was 90%. Moreover, the pore size was distributed in the range of 30 to 100 $\mu\text{m}$ , and the average thereof was 60 $\mu\text{m}$ . The pore size in this range is appropriate in maintaining microorganisms within the porous material, and preferably used as microbial carriers.

Moreover, the apparent specific gravity of the porous spherical particles in a moistened state obtained in each of the examples was in the range of approximately 1.017 to 1.019 per 10 samples. Here, the particles of Example 3, which were hollow particles, have a specific gravity of approximately 1.008 that was smaller than the above-mentioned apparent specific gravity. After having been subjected to centrifugal dehydration, the moisture rate was 50.4%, and the 50% compressive stress was  $20 \times 10^3 \text{ N/m}^2$ . When 20 of them were put onto water in a beaker being shaken, all the particles gradually sank under the water surface in 3 minutes 28 seconds after having floated on the water surface for a while.

(Pressing tests)

Next, the porous spherical particles obtained in the respective examples were dried for one hour at 60°C. The moisture rate was 3.0 %. This was pressed under a pressure of  $4.9 \times 10^6 \text{ N/m}^2$ , with the result that this was compressed into a diameter of 0.75 to 1.5 mm. When 20 of them were put onto water being shaken, they smoothly absorbed water and swelled, and all of them sank under the water surface in 8 seconds. When the sunk particles were taken out and measured in a moistened state of a moisture rate of 50 %, all of them restored their original shape and size before being put into water. In other words, it was confirmed that when put into water, they were allowed to quickly swell two to four times the original volume.

In contrast, 20 of samples prior to the compressing process were put onto water in a beaker being shaken, all the particles were allowed to float on the water surface. Even if the surface of the particle absorbed water, since air inside thereof was not released, no particles sank under the water surface even after two hours of the shaking process.

(Durability tests)

Moreover, a simulation test assuming the fluidizing state inside a bioreactor was carried out; and the porous spherical particles, obtained in the respective examples and comparative example 7, were loaded into a container having a diameter of 150 mm and a height of 400 mm so as to be set to 10% in volume with respect to the amount of water, and these were fluidized under aeration in water so that the particles were uniformly dispersed and fluidized. After this fluidizing process had been continued for one month, the particles were taken out and observed. The results shows that neither abrasion nor damages were observed on the particles related to the examples, and it is confirmed that these were superior in abrasion resistant property.

However, abrasion was observed on the particles of comparative example 7 that had an insufficient degree of acetalization.

Furthermore, an accelerated test was carried out so as to compare the abrasion resistant property to a single member made from another material; and water resistant sand paper (#10) was affixed to the inner faces of the side walls of the same test container as described above, and the various carriers were individually loaded thereto so as to be set to 10% in volume with respect to the amount of water so that these were stirred and fluidized in water. In the stirring process, a stirring blade put into the water vessel was rotated at a speed of 300 rpm so that the carriers were mechanically fluidized so as to be subjected to frictional contact against the inner walls. This fluidizing process was continued for a week, and the state of the carriers were observed in association with time. No abrasion due to friction was observed on the porous spherical particles of the present invention, and it is confirmed that these are superior in abrasion resistant property.

In contrast, with respect to other materials, such as polyurethane sponge, cellulose sponge and spherical gels of calcium alginate, having a diameter of 3 mm, it was confirmed that the surface thereof was scratched and subjected to abrasion in any of these materials 24 hours later. The abrasion further developed one week later, the size of any one of the materials had become not more than half the original size. Additionally, with respect to the gel of calcium alginate, an aqueous solution of alginic acid soda having a concentration of 1 % was dropped into an aqueous solution having a concentration of 2% and solidified; thus, the tested gel was prepared.

(Biodegradability test for carriers)

Moreover, the particles were loaded into a polypropylene container having a number of holes in 2mm mesh so as to be set to 10%, and this was dipped into an activated sludge process aeration vessel together with the container. One year later, this container was taken out, and the polyvinyl acetal particles inside the container were observed. The results show that no dimensional variations due to abrasion were observed. Moreover, aerobic bacteria adhered to the particle surface in high density, and no erosion of the carriers due to the bacteria was observed.

(Preparation of inclusive fixed carriers)

A mixture was separately formed by mixing activated sludge condensed into approximately 50g/l by means of centrifugal separation and an alginic acid soda of 2% at a volume ratio of 1:1. This was impregnated into the porous spherical particles obtained in the respective examples through the above-mentioned processes. In order to increase the amount of impregnation, the mixed solution was flowed in a vacuum.

This microorganism inclusive member, thus obtained by allowing the porous spherical particles to be impregnated with the mixed solution of alginic acid soda and microorganisms, was added by 5 % of an aqueous solution of calcium chloride and stirred, and this was allowed to react for about three hours in this state. Thus, the alginic acid soda contained in the polyvinyl acetal porous material became insoluble, with the result that this was fixed with the microorganisms being included.

The microorganism inclusive fixed carrier thus obtained had an arrangement in which the alginic acid-based gel adhered to the pores and surface of the porous spherical particles; thus, in the same manner as the polyvinyl acetal porous material, it had a superior hydrophilic property and was superior in flexibility and elasticity in a wet state. Moreover, since this material is a porous spherical particle polyvinyl formal and superior in a hydrophilic property, the porous spherical particles are allowed to have an affinity for the gel, and the gel is uniformly present in the particles. Moreover, since it has a high porosity and a three-dimensional mesh structure, the ratio of the gel in the particle is maintained in a high level.

A simulation test assuming the fluidizing state inside a bioreactor was carried out; and the resulting microorganism inclusive fixed carriers were loaded into a container having a diameter of 150mm and a height of 400mm, and these were fluidized under aeration in

water so that the particles were uniformly dispersed and fluidized. After this fluidizing process had been continued for one month, the particles were taken out and observed. The results show that neither abrasion nor damages were observed, and it is confirmed that these were superior in abrasion resistant property. Moreover, no erosive deterioration on the porous spherical particles caused by microorganisms was observed, and it is confirmed that the service life of the carrier can be maintained for a long time.

The results of the above-mentioned examples and comparative example show that, in order to manufacture the porous spherical particles through the manufacturing method of the present invention, the water-soluble polymer having a property of gelling needs to be blended at an appropriate concentration, and that in order to retain its shape, it needs to be acetalized. For example, in comparisons between Example 1 and Comparative Example 1 as well as Example 2 and Comparative Example 2, in the case when no sodium alginate was contained in the dropping liquid, the droplets derived from the dropping process failed to retain their shape, resulting in cloud-shaped particles.

Moreover, as shown in Example 3, for example, when the first reaction liquid and the dropping liquid of Example 1 were used in the dropping process in a reversed manner, hollow particles were obtained. In this case, it was confirmed that the lower the concentration of polyvinyl alcohol, the cleaner the particles.

Moreover, as clearly shown by Examples 7 and 8, the addition of a pore-forming agent such as starch to the dropping liquid made it possible to control the porosity and pore size of the spherical particles. In the case when starch was used as the pore-forming agent, the starch was allowed to swell by setting the temperature of the first reaction liquid slightly higher, and the amount of blend of sulfuric acid to the second reaction liquid was set slightly higher since the starch consumed sulfuric acid; thus, it was possible to obtain more preferable results. Moreover, it was confirmed that the temperature of the second reaction liquid was raised slightly so that it became possible to greatly shorten the time of acetalization.

Furthermore, all the particles obtained through the above-mentioned examples were superior in the application as microorganisms fixing carriers, and provided preferable results in factors, such as the fluidity, specific gravity, abrasion resistance, weather (light) resistance, anti-microorganism degradability. Here, when the spherical particles of the

present invention were compressed, the permeability with water was improved, thereby allowing easier handling of the particles. However, in the case of a low degree of acetalization, such as not more than 30 % by mol, the abrasion resistance was lowered.

#### Industrial Applicability

The porous spherical particles of the present invention are porous spherical particles having a polyvinyl acetal resin as their skeleton; therefore, they have high mechanical strength and abrasion resistance so that they can be used in various applications, such as microbial carriers, liquid retainers and plant supporting members in water culture for agricultural products, culture media for animal and plant cells, artificial water moss, soil improving members, water fluidizing washing members, and water fluidizing massage members. In particular, in the case of the applications of microbial carriers, especially, fluidized bed type microbial carriers, these particles are less susceptible to abrasion due to friction between the carriers as well as friction against inner walls of a reaction vessel, making it possible to lengthen the service life of the carriers. Moreover, in addition to a better affinity for microorganisms, they are superior in factors, such as fluidity, specific gravity, weather (light) resistance, and anti-microorganism degradability so that they are preferably used as fluidized bed type microbial carriers and microorganism inclusive fixed carriers.

Moreover, in the case of the porous spherical particles having a polyvinyl acetal resin having a uniform particle size close to a true globe as their skeleton, they are easily filled into various containers, have an improved abrasion resistance, and also improve the fluidity when used as fluidized bed type microbial carriers.

Furthermore, in the manufacturing method of the porous spherical particles of the present invention, the reaction is made in one stage by utilizing the shape of droplets so that the reaction time and the post processes can be shortened greatly, and a large amount of spherical particles can be manufactured continuously. Therefore, the manufacturing time can be shortened greatly, materials having superior strength can be obtained, and particles generally having a uniform, desired particle size can be obtained. Moreover, different from conventional methods, it is possible to reduce losses in the post processes, and consequently to improve the yield and it is also possible to reduce the space required



for the reaction. Furthermore, since hollow polyvinyl acetal porous spherical particles can be obtained, they are, in particular, preferably applied to the fluidized bed type microbial carriers.

## CLAIMS

1. A porous spherical particle of which skeleton is made of a polyvinyl acetal-based resin.
2. A porous spherical particle comprising a sponge of which skeleton is made of a polyvinyl acetal-based resin.
3. A porous spherical particle set forth in claim 1 or 2 wherein the polyvinyl acetal-based resin is polyvinyl formal and the degree of formalization is from 30 to 85% by mole.
4. A porous spherical particle set forth in any one of claims 1 to 3 wherein the porosity of the porous spherical particle is from 50 to 98%.
5. A porous spherical particle set forth in any one of claims 1 to 4 wherein the particle is a hollow material.
6. A porous spherical particle set forth in any one of claims 1 to 5 wherein the particle carries on its surface a coating having pores and the inside of the particle has a porous structure.
7. A porous spherical particle set forth in any one of claims 1 to 6 wherein the apparent specific gravity of the porous spherical particle in its hydrated state is from 1.0 to 1.2.
8. A porous spherical particle set forth in any one of claims 1 to 7 which is a particulate material wherein the size of the porous spherical particle in its hydrated state is from 1 to 20mm.
9. A porous spherical particle set forth in any one of claims 1 to 8 wherein the average diameter of the pores is from 20 to 300  $\mu$ m.
10. A compressed porous spherical particle of which skeleton is made of a polyvinyl acetal-based resin.
11. A compressed porous spherical particle set forth in claim 10 which is a spongy porous spherical particle having a water content of 10% or less and, when immersed in water, which rapidly swells to a 2- to 10-fold volume and of which size in the hydrated state becomes 1 to 20mm.
12. A microbial carrier being characterized in that porous spherical particles set forth in any one of claims 1 to 11, of which skeleton is made of a polyvinyl acetal-based

resin, are used as the microbial carrier.

13. A microbial carrier set forth in claim 12 wherein microbes are immobilized on the surface and/or in the pores of the porous spherical particles set forth in any one of claims 1 to 11.
14. A microbial carrier set forth in claim 12 wherein microbes are immobilized by inclusion on the surface and/or in the pores of the porous spherical particles set forth in any one of claims 1 to 11 using a microbe-immobilizing agent.
15. A microbial carrier set forth in claim 14 wherein the microbe-immobilizing agent comprises sodium alginate as a principal ingredient.
16. A bioreactor using a microbial carrier set forth in any one of claims 12 to 15.
17. A process for producing porous spherical particles, the process being characterized in that an aqueous solution comprising a mixture of a water-soluble polymer having the property of gelling in an acidic solution, polyvinyl alcohol and an aldehyde is dropped into an acidic solution to gel the droplets while allowing the reaction between the polyvinyl alcohol and the aldehyde in the droplets in order to obtain porous spherical particles of which skeleton is made of a polyvinyl acetal-based resin.
18. A process for producing porous spherical particles, the process being characterized in that an aqueous solution comprising a dissolved mixture of a water-soluble polymer having the property of gelling via an ion exchange reaction and polyvinyl alcohol is dropped into an aqueous solution of a polyvalent metal salt to gel the droplets by the ion exchange reaction and thereby form gel spherical particles containing polyvinyl alcohol, and said gel spherical particles are then added into an acid solution containing an aldehyde to allow the polyvinyl alcohol included in said gel spherical particles to react with the aldehyde, thereby obtaining porous spherical particles of which skeleton is made of a polyvinyl acetal-based resin having a degree of acetalization of 30 to 85% by mole.
19. A process for producing porous spherical particles set forth in claim 18, the process being characterized in that the aqueous solution comprising a dissolved mixture of a water-soluble polymer capable of gelling and polyvinyl alcohol comprises 0.5 to 5% by weight of the water-soluble polymer capable of gelling and further comprises 5 to

20% by weight of the polyvinyl alcohol.

20. A process for producing porous spherical particles, the process being characterized in that an aqueous solution of a polyvalent metal salt is dropped into an aqueous solution comprising a dissolved mixture of a water-soluble polymer having the property of gelling via an ion exchange reaction and polyvinyl alcohol to coagulate it by the reaction between the droplets of the polyvalent metal salt and the water-soluble polymer and thereby form gel spherical particles of which peripheral part contains a mixture of the gel of the water-soluble polymer reacted with the polyvalent metal salt and the polyvinyl alcohol, and said gel spherical particles are then added into an acid solution containing an aldehyde to allow the polyvinyl alcohol included in said gel spherical particles to react with the aldehyde, thereby obtaining hollow porous spherical particles of which skeleton is made of a polyvinyl acetal-based resin.
21. A process for producing porous spherical particles set forth in claims 17 to 20 wherein the aqueous solution described in claims 17 to 20, which comprises at least a dissolved mixture of a water-soluble polymer having the property of gelling via an ion exchange reaction and polyvinyl alcohol, contains a pore-forming agent.
22. A process for producing porous spherical particles set forth in claim 21 wherein the pore-forming agent is starch.
23. A process for producing porous spherical particles set forth in claims 17 to 20 wherein the porous spherical particles of which skeleton is made of a polyvinyl acetal-based resin are obtained by removing the gel contained in the spherical particles described in claims 17 to 20.
24. A process for producing compressed porous spherical particles which process comprises pressing the spherical particles obtained in claims 17 to 20 in order to push out gases included in the pores of the porous spherical particles and also to compress the particles to a half to tenth volume.

## CLAIMS IN THE AMENDMENT

[Received by the international bureau on December 29, 1997 (29.12.97); the original claims 1, 2, 12, 17, 18, and 20 were amended; the other claims contain are unchanged (4 pages).]

1. (As amended) A porous spherical particle comprising an elastic sponge of which skeleton is made of a polyvinyl acetal-based resin.
2. (As amended) A porous spherical particle set forth in claim 1 which comprises a sponge having communicating holes as its pores.
3. A porous spherical particle set forth in claim 1 or 2 wherein the polyvinyl acetal-based resin is polyvinyl formal and the degree of formalization is from 30 to 85% by mole.
4. A porous spherical particle set forth in any one of claims 1 to 3 wherein the porosity of the porous spherical particle is from 50 to 98%.
5. A porous spherical particle set forth in any one of claims 1 to 4 wherein the particle is a hollow material.
6. A porous spherical particle set forth in any one of claims 1 to 5 wherein the particle carries on its surface a coating having pores and the inside of the particle has a porous structure.
7. A porous spherical particle set forth in any one of claims 1 to 6 wherein the apparent specific gravity of the porous spherical particle in its hydrated state is from 1.0 to 1.2.
8. A porous spherical particle set forth in any one of claims 1 to 7 which is a particulate material wherein the size of the porous spherical particle in its hydrated state is from 1 to 20 mm.
9. A porous spherical particle set forth in any one of claims 1 to 8 wherein the average diameter of the pores is from 20 to 300 $\mu$ m.
10. A compressed porous spherical particle of which skeleton is made of a polyvinyl acetal-based resin.
11. A compressed porous spherical particle set forth in claim 10 which is a spongy porous spherical particle having a water content of 10% or less and, when immersed in water, which rapidly swells to a 2- to 10-fold volume and of which size in the

hydrated state becomes 1 to 20 mm.

12. (As amended) A microbial carrier being characterized in that porous spherical particles set forth in any one of claims 1 to 11 are used as the microbial carrier.
13. A microbial carrier set forth in claim 12 wherein microbes are immobilized on the surface and/or in the pores of the porous spherical particles set forth in any one of claims 1 to 11.
14. A microbial carrier set forth in claim 12 wherein microbes are immobilized by inclusion on the surface and/or in the pores of the porous spherical particles set forth in any one of claims 1 to 11 using a microbe-immobilizing agent.
15. A microbial carrier set forth in claim 14 wherein the microbe-immobilizing agent comprises sodium alginate as a principal ingredient.
16. A bioreactor using a microbial carrier set forth in any one of claims 12 to 15.
17. (As amended) A process for producing porous spherical particles comprising an elastic sponge of which skeleton is made of a polyvinyl acetal-based resin, the process being characterized in that an aqueous solution comprising a mixture of a water-soluble polymer having the property of gelling in an acidic solution, polyvinyl alcohol and an aldehyde is dropped into an acidic solution to gel the droplets while allowing the reaction between the polyvinyl alcohol and the aldehyde in the droplets.
18. (As amended) A process for producing porous spherical particles comprising an elastic sponge of which skeleton is made of a polyvinyl acetal resin having a degree of acetalization of 30 to 85% by mole, the process being characterized in that an aqueous solution comprising a dissolved mixture of a water-soluble polymer having the property of gelling via an ion exchange reaction and polyvinyl alcohol is dropped into an aqueous solution of a polyvalent metal salt to gel the droplets by the ion exchange reaction and thereby form gel spherical particles containing polyvinyl alcohol, and said gel spherical particles are then added into an acid solution containing an aldehyde to allow the polyvinyl alcohol included in said gel spherical particles to react with the aldehyde.
19. A process for producing porous spherical particles set forth in claim 18, the process being characterized in that the aqueous solution comprising a dissolved mixture of a water-soluble polymer capable of gelling and polyvinyl alcohol comprises 0.5 to 5%

by weight of the water-soluble polymer capable of gelling and further comprises 5 to 20% by weight of the polyvinyl alcohol.

20. (As amended) A process for producing hollow porous spherical particles comprising an elastic sponge of which skeleton is made of a polyvinyl acetal-based resin, the process being characterized in that an aqueous solution of a polyvalent metal salt is dropped into an aqueous solution comprising a dissolved mixture of a water-soluble polymer having the property of gelling via an ion exchange reaction and polyvinyl alcohol to coagulate it by the reaction between the droplets of the polyvalent metal salt and the water-soluble polymer and thereby form gel spherical particles of which peripheral part contains a mixture of the gel of the water-soluble polymer reacted with the polyvalent metal salt and the polyvinyl alcohol, and said gel spherical particles are then added into an acid solution containing an aldehyde to allow the polyvinyl alcohol included in said gel spherical particles to react with the aldehyde.
21. A process for producing porous spherical particles set forth in claims 17 to 20 wherein the aqueous solution described in claims 17 to 20, which comprises at least a dissolved mixture of a water-soluble polymer having the property of gelling via an ion exchange reaction and polyvinyl alcohol, contains a pore-forming agent.
22. A process for producing porous spherical particles set forth in claim 21 wherein the pore-forming agent is starch.
23. A process for producing porous spherical particles set forth in claims 17 to 20 wherein the porous spherical particles of which skeleton is made of a polyvinyl acetal-based resin are obtained by removing the gel contained in the spherical particles described in claims 17 to 20.
24. A process for producing compressed porous spherical particles which process comprises pressing the spherical particles obtained in claims 17 to 20 in order to push out gases included in the pores of the porous spherical particles and also to compress the particles to a half to tenth volume.